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MONTANA ENERGY CONSERVATION PLAN

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SMALL SCALE HYDROPOWER

A report to the
Montana Energy Advisory Council

Prepared for

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Butte, Montana

By

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15.0 SMALL SCALE WATER POWER

Water power is one of the world's oldest energy technologies. The solar evaporation and condensation cycle creates a renewable, visible and usually consistent flow of potential energy that can be tapped in several ways. Large, simple, low-speed water wheels have been used throughout history to provide mechanical energy for such things as wood cutting and milling of agricultural products. Today there is an emphasis on electrical generation using small, high-speed water turbines.

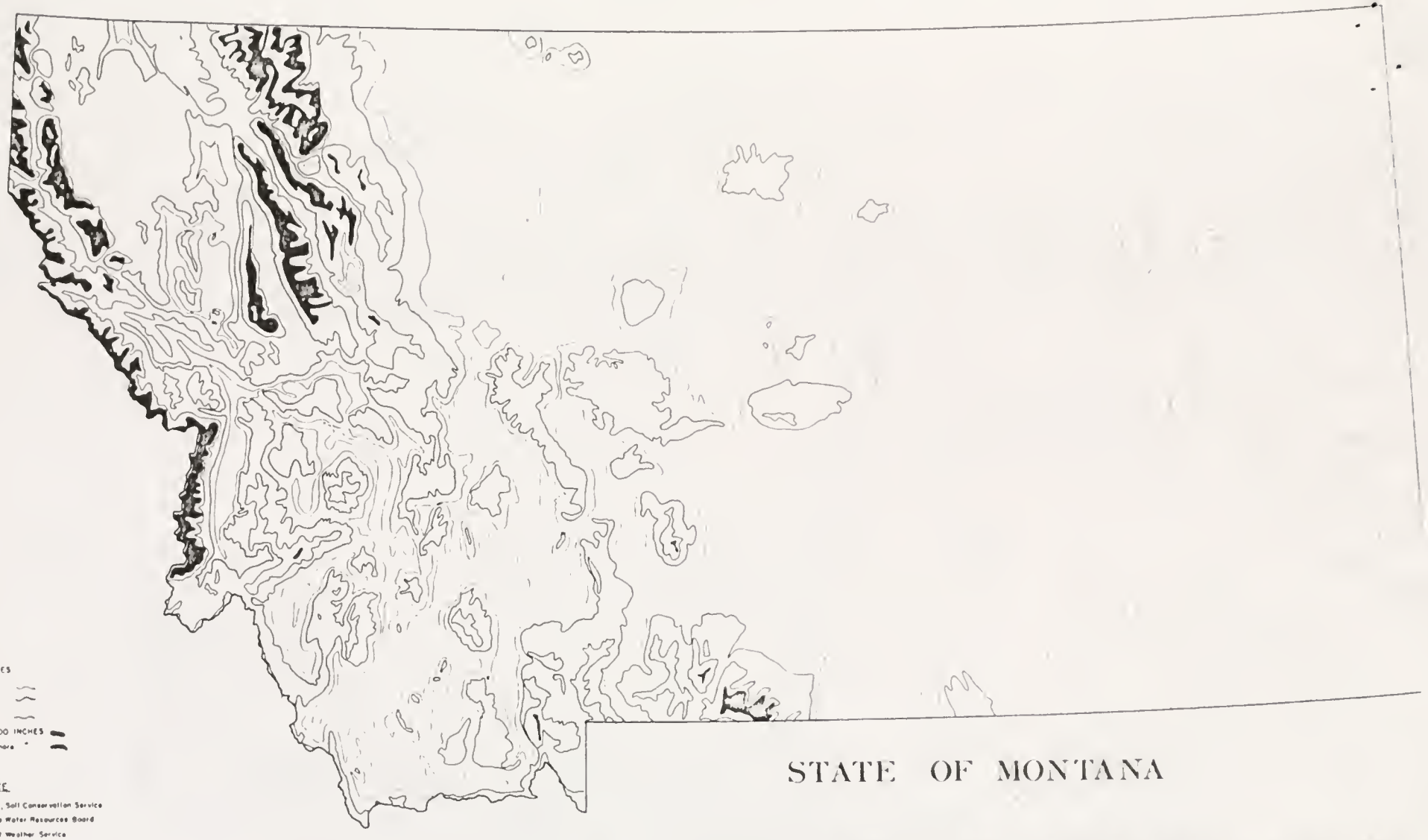
Most of the large and easily developed hydroelectric sites have already been tapped in this country. The potential for small-scale water-powered systems has not yet been considered because of conventional, large-scale economic thinking. There are abundant untapped streams and waterfalls in Montana, particularly in Western Montana where the rainfall is greatest. (See map, figure 15.1) Many small communities and some individuals could harness the diffuse power from this falling water to supply their electrical demands. Some mechanical energy needs can also be met with simple water wheels.

15.1.1

The gross theoretical horsepower (THP) produced by a given stream of water is a function of the head H (distance of water fall in feet) and the flow rate Q (given in cubic feet per second). When corrected for these units the formula is

$$THP = \frac{Q \times H}{8.82}$$

To convert to kilowatts, THP x 0.7457 = KW. The gross power must then be adjusted for conversion efficiencies of the turbine itself, as well as mechanical and electrical linkages. Overall efficiencies range from 50% to 80%. Seasonal variations in stream flow and other disruptions further reduce the potential net output to 40% of capacity (40% plant factor).



STATE OF MONTANA

AVERAGE ANNUAL PRECIPITATION

FIGURE 15.1

15.1.2

There are two basic classifications of hydro power -- water turbines and water wheels. Water turbines spin at high speed and are used for electrical generation. Three small-scale turbines are considered here: The reaction wheel, cross flow, and impulse. Water wheels, used for high torque mechanical purposes (cutting, milling, etc.) are classified into three types: overshot, breast and undershot.

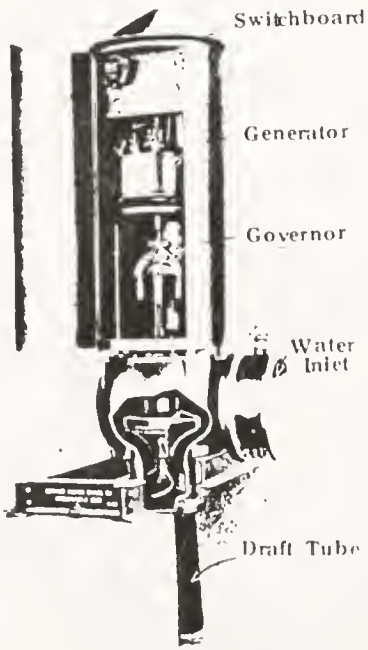
15.2 Water turbines

15.2.1 Reaction wheel

A propeller is turned by the fall of water through a duct or pipe in which the wheel is confined. This is the most compact type of unit for power output. Large units can be coupled directly to a generator, but small units must be geared up to match a high-speed generator. The disadvantages of the reaction wheel are rapid corrosion with silted water, and high leakage and friction losses, especially in small units.

The James Leffel & Co. of Springfield, Ohio, manufactures a line of reaction wheel turbines called Hoppes. Sizes range from .5 to 10 KW using a head from 8 to 25 feet. The 10 KW unit costs $11,000. Life expectancy ranges from 10 to 15 years. Installation can take from 2 to 4 weeks. (Leffel, personal communication)

Fig. 5
1 K. W. Unit on a Ranch in Montana.



Cutaway Section Showing Governor Control Valve.

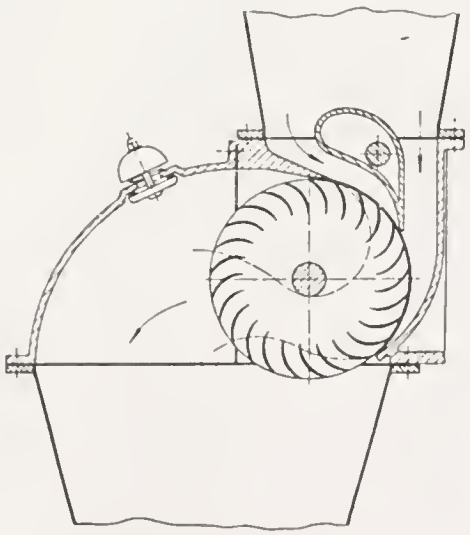
THE JAMES LEFFEL & CO.

FIGURE 15.2

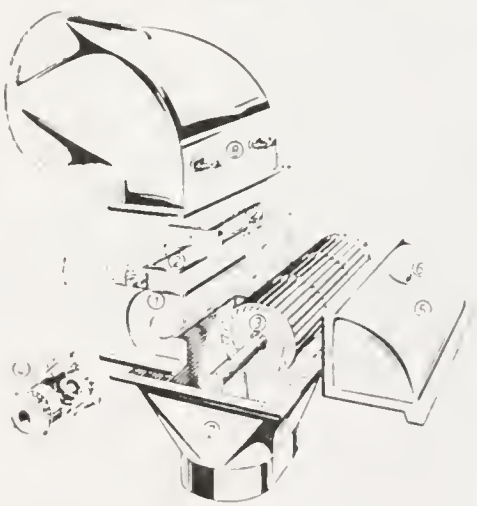
15.2.2 Cross flow

The cross flow turbine (also called Mitchel or Banki) can be constructed with moderate metal-working skills and tools by a small cottage industry (VITA, 1970). A German manufacturer (Ossberger-Turbininfabrik) produces these units ranging in size from 8.5 KW to 220 KW. The design is essentially the same for a wide range of flows and heads (15 to 100 feet). The curved blades in this design are designed to be hit twice by the falling water; three-quarters of the power is taken off the first pass, and one-quarter the second pass.

The disadvantages are lower efficiency at low speed and load, also the complex blade arrangement can get easily clogged. Costs range from $1650/KW for small units to $2000/KW for larger ones (above 40 KW). Some ponding is necessary to ensure a steady flow. Installation time is about two weeks, and life expectancy is assumed to be 20 to 30 years.



Patented OSSBERGER cross-flow
Vertical admission



Miniature power stations like this 8.5 kVA plant in Marianhill (South Africa) are, despite their modest output, completely self-contained, automatic hydro-electric generating sets which are only shut down once a year for a change of oil and grease. Year in, year out, day and night, they deliver any power needed at constant voltage and frequency, of course. No matter whether only one small lamp is burning or whether full power is demanded, the set always supplies the right amount of power. If all loads are disconnected, the set continues to run at no-load speed, ready at any time to instantly generate the power required when loads are connected.

Information Free
from:
Ossberger-Turbinenfabrik
D-8832 Weissenherg i. Bay, P.O. B ·x 425
Bayern, Germany

FIGURE 15.3

15.2.3 Impulse

The impulse or Pelton wheel works by the force of a jet of water acting on cups mounted on the perimeter of a small wheel. The advantages are: no damming required, longer operational life (40 years), and the high-speed shaft can be directly coupled to a generator. The disadvantages are: sand and silt in the water erodes the cups, and a high head is needed (the higher the better; 50 to 1000 feet is a moderate range; some installations go much higher.) The power output ranges from 1 to 400 KW for the small units. Price ranges from $1000/KW for small units (1 to 35 KW) down to about $750/KW for larger turbines. The auxiliary equipment needed is mainly the long pipe that carries a portion of a stream down to power the turbine. Installation time is about one week (Delp, personal communication).

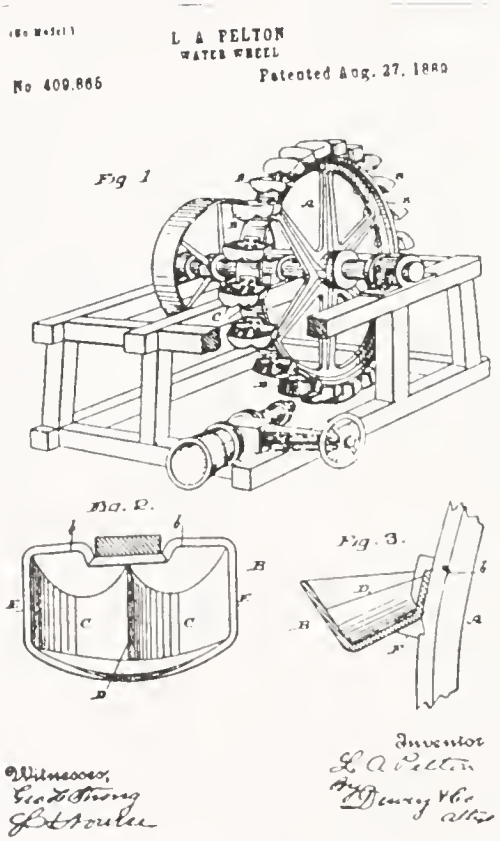


FIG. 24. Details of original patent by L. A. Pelton, 1889

FIGURE 15.4

15.3 Water wheels

15.3.1 Overshot wheel

Water flows through a sluice gate to the top of a wheel of buckets, causing the wheel to turn by the weight of the water and, to a slight extent, by the impulse of the water hitting the bucket. Because of the ease of construction, installation, and operation, this water wheel has been favored for many years. It is unaffected by sand, silt or minerals. The 1 to 20 KW output can be produced by a wheel whose diameter is .75 x head (heads range from 10 to 30 feet). The costs of these water wheels are difficult to determine. A rough guess has been made of $1000/KW for comparison purposes. The cost of auxiliary equipment given in the table is only to be used as a comparison of one system to the next.

15.3.2 Breast wheel

Water flows down into buckets that trap the water by the concrete breast that is formed to fit close to the wheel. Air vents must be kept clear in the buckets to allow the water to enter. This is less efficient than the overshot and more expensive because of the careful breast construction.

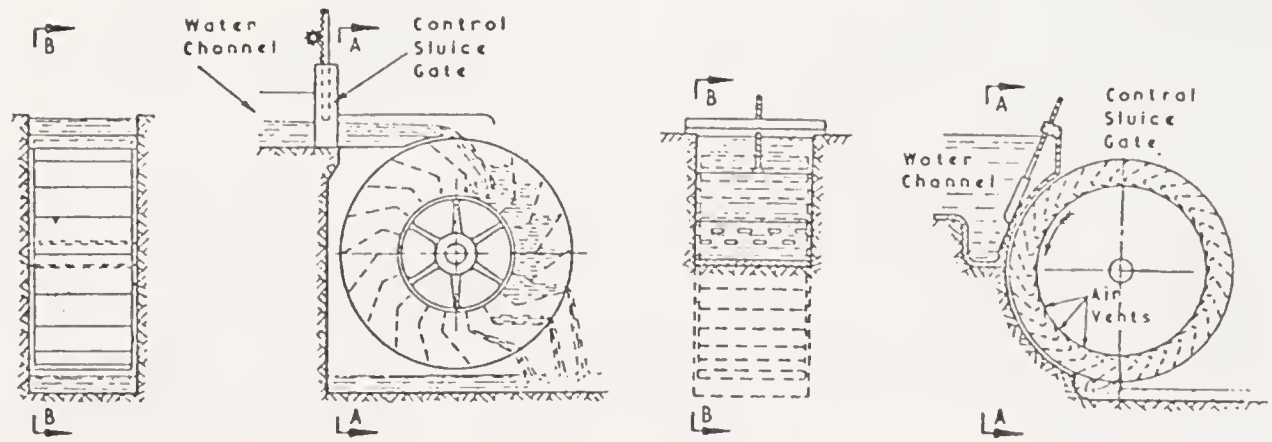


FIGURE 15.5

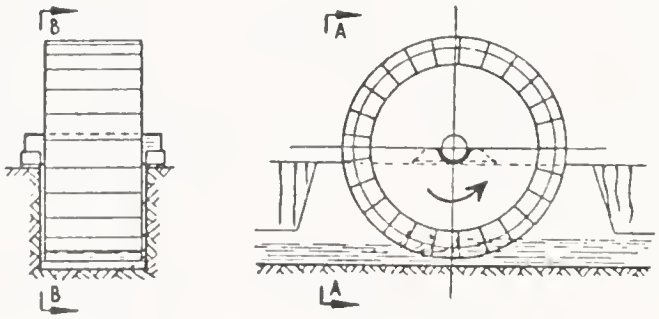
15.3.3 Undershot wheel

This is the simplest of all water wheels. As water flows by, paddles pick up the energy in the stream and produce mechanical energy. The low efficiency is balanced by the low cost of construction and installation. The environmental impact of the undershot wheel is negligible.

The use of water wheels in Montana will probably be very restricted for several reasons:

1) These are not factory produced; therefore, to reduce the cost they must be fabricated by do-it-yourself operations. The life expectancy, operation, and maintenance are therefore dependent on the quality of construction and installation.

2) Due to the nature of Montana's weather, these wheels will usually produce only seasonal power. This will probably match several mechanical uses which are also seasonal. However, the severe cold climate imposes design constrictions that must be considered.

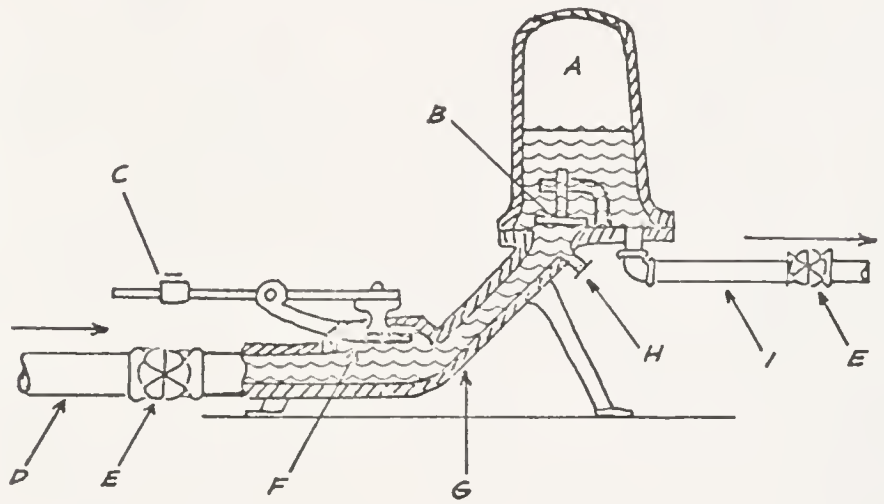


UNDERSHOT WHEEL.

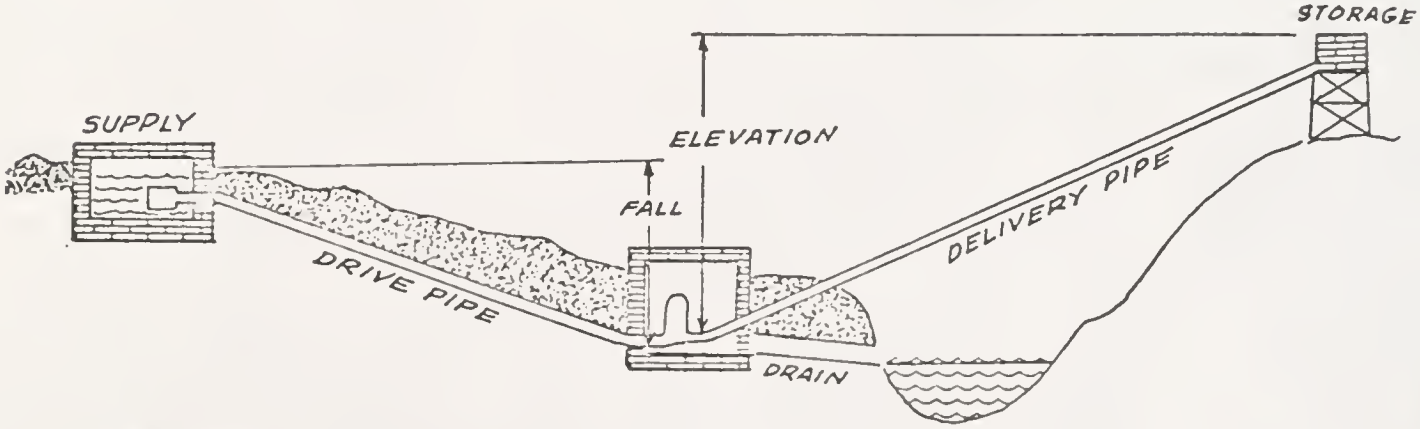
FIGURE 15.6

15.4 Hydraulic rams

A hydraulic ram is a water pumping device that uses the energy in a small head (5 to 10 feet) and flow (1 to 5 cf/m) to raise one seventh of the flow up to 5 times the head (proportions of these same quantities can be used for calculation purposes). The total installed cost of $900 to $1200 for a household unit (Delp, private communication) is about five times the cost of an electrical pump. However, this cost can be paid back with the "free" energy provided by the head of water. This simple device could be used in many locations where there is a need for water, or to pump some water back to be used again in a water power application.



A. AIR CHAMBER
B. CHECK VALVE
C. ADJUSTMENT WEIGHT
D. DRIVE PIPE
E. GATE VALVE
F. OUTSIDE VALVE
G. CAST IRON BASE
H. AIR FEEDER VALVE
I. DELIVERY PIPE



A. COMMON ARRANGEMENT OF DRIVE PIPE, RAM AND STORAGE

FIGURE 15.7

15.5

To evluate the various small-scale hydro systems, the following criteria have been used:

1) context -- the usefulness of the system for electrical or mechanical end use
2) size -- the rated energy output in KW. The range of each system is given as well as the particular size that is used for evaluation and comparison.
3) head -- the distance the water must fall to generate the desired power output.
4) flow -- the cubic feet per minute of water flowing through the water system.
5) efficiency -- the comparison of theoretical power with actual delivered power (losses due to mechanical friction, generator, pipe friction, etc.)
6) capital cost -- the cost of the unit divided by the maximum power capacity.
7) auxiliary cost -- the auxiliary equipment and facilities needed for a complete system include pipe, dam, valves, gates, foundation and other concrete work. Most of the numbers used here are estimates that should only be viewed as comparisons.
8) yield -- the yearly outpit in KWh.
9) total capital cost -- the total cost of the system plus auxiliary cost is divided by the yearly BTU output to get cost per million BTU per year.
10) energy cost = $\frac{CC \times FCR}{PF \times 8.76} + O + M$

where: CC = capital cost + auxiliary cost

FCR = annual Fixed Charge Rate (15% is used here)

PF = Plant Factor (40% used here)

O + M = Operations and Maintenance (2 mills/average KWh is used here)

(large hydroelectric systems have an O+M cost of .002 mills/KWh)

Table 15.5.2

WATER WHEELS

	overshot	breast	undershot
context	mechanical	mechanical	mechanical
size range	1-20kw	1-20kw	1-10kw
size eval	2 kw	2 kw	2 kw
head range	10-30'	6-15'	1-15'
flow range	3→ cfm	3→ cfm	3→ cfm
efficiency	60-85%	40-70%	35-45%
capital cost $/kw	1,000	1,000	800
auxiliary cost $/kw	300	500	200
yield kwh/yr	17520	17520	17520
capital cost $/mmBTU/yr	43	50	33
energy cost $/kwh	$0.113	$0.13	$0.088
environmental notes	ponding needed	ponding needed	very low impact; no ponding needed

Table 15.5.1

WATER TURBINES

	Reaction (Hoppes)	Cross flow (Banki Mitchell)	Impulse (Pelton)
context	electric generation	electric	electric
size range size eval.	0.5 - 10 kw 10 kw	8.5 - 220 kw 50 kw	1-400 kw 100 kw
head range head eval.	8-25 feet 25'	15-150 feet 100'	50-4,000 feet 400'
flow range flow eval.	70 - 500 cfm 500 cfm	400-1000 cfm 700 cfm	35-400 cfm 215 cfm
efficiency of prime overall	80% 57%	60-85% 50%	80-94% 82%
capital cost/kw auxiliary cost/kw	$1100 $175	$1300 $700	$750 $150
yield (kwh/yr)	8.76×10^4	4.38×10^5	8.76×10^5
total capital cost	$43/mmBTU/yr	$67/mmBTU/yr	$30/mmBTU/yr
energy cost	$ .55/kwh	$4.28/kwh	$3.85/kwh
environmental notes	ponding needed for low flow streams	ponding needed for low flow streams	no ponding needed; long pipe needed to carry water down.

15.6 Conclusion

15.6.1

A definitive assessment of the hydroelectric potential for the whole state of Montana is beyond the scope of this investigation. The potential for large-scale hydropower projects has been made by the Army Corps of Engineers. They have identified over 23 sites in the drainage areas of the Kootenai, Yaak, and Clark Fork Rivers that could produce an average annual energy output of over 1000 mw, the average output per installation is 48 mw with a range of from 7 to 268 mw.

The Corps has a difficult time identifying and quantifying these large installations; estimating the potential for small-scale hydro development will require a thorough hydrological investigation. "Every case has to be judged individually. The essential factors include local conditions, interest rates, and the trends of construction costs and fuel prices, assessed as accurately as they can be done at the time." (Patton, 1961)

15.6.2

The ecological disruptions caused by dam construction severely limit this practice as a widespread energy storage technique. The high head systems (such as the impulse turbine) do not require a dam and therefore are very applicable in the western part of the state where the rainfall is heavy and there are mountains providing high potential head. When done carefully (i.e., no access roads), hydro development can be done in the national forests.

15.6.3

An assessment needs to be made on the nearness of mechanical end uses in sectors such as the lumber and agricultural industry to seasonal or year-round streams. Direct mechanical conversion, using the best of our refined industrialized technology, can put water wheels and many water turbines to work in turning the wheels of business and industry.

15.6.4

The installation of 5mw installed hydroelectric capacity per year would cost in the neighborhood of seven million dollars. Only about 2% of the total cost is for installation labor. This assumes a large proportion of owner/builder construction. This would account for about 225 jobs in the manufacture of these units and 233 jobs relating to the installation.

15.7 Institutional constraints

The watershed of Western Montana is presently managed by a network of utilities and the Bonneville Power Administration. This regulation is aimed at maximizing the power output of all the dams on the Columbia River system (Montana, Idaho, Washington, Oregon, British Columbia) (NETL et al., 1976). There are substantial reserves and surpluses in most years which more than adequately meet all the needs of the entire Northwest area. These institutions have a federal mandate to completely manage and oversee the development of hydro resources in the system. The rising use of small-scale hydro power by individuals would not dramatically affect the overall system. If the people of Western Montana or any other watershed areas were to begin using small-scale hydro, a regulating question would arise.

15.8 Environmental impacts

Land use/aesthetics: The principal environmental problems with hydro power have been the impacts on land area, water quality and aesthetics. While small-scale developments will not create large problems, every potential hydro site has to be carefully evaluated. The installation of thousands of feet of pipe to run an impulse wheel creates fewer problems than a dam. Some small-scale damming may be allowed; but the ecological disturbance during construction and the eventual filling of the reservoir with silt prohibit the extensive practice of this type of energy storage.

15.9 Biological impacts

The impact on flora and fauna which live in or near a stream could also be substantial. If spawning of fresh water trout and other fish is interrupted, there could be serious impacts on sport fisheries and the overall ecosystem. The diverting of a major part of stream flows could also have negative impacts on flora in areas that depend on that water.

15.10 Hydrological impacts

The overall hydrological impacts would probably be minor if design criteria for the systems include spillways and devices to ensure that water was rediverted into original channels.

15.11 Positive impacts

Careful development of high head systems will help to stabilize stream flows and add oxygen to the water. Exploitation of small-scale technologies can provide greater energy from a given watershed, thereby reducing the need for other kinds of generating capacities with detrimental environmental impacts.

15.12 Human impacts

The existence of small power output hydroelectric projects would open many new areas for development which have previously been infeasible. New communities could be developed whose electrical power requirements matched the hydro-electrical production in the area.

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